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Certification under 37 CFR 1.10 (if applicable)

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Assistant Commissioner for Patents
Washington, D.C. 20231

Sir:

Transmitted herewith for filing is the patent application, including 5 sheets of formal drawings of inventor: George Kirkman for LINEARIZED TRAVELING WAVE TUBE CIRCUIT WITH PRE-DISTORTION LINEARIZER.

The filing fee for this application is calculated below:

	CLAIMS AS FILED			
	NUMBER FILED	NUMBER EXTRA	RATE	
Basic Fee				\$ 690.00
Total Claims	19 -20 =	0 x	\$ 18.00	\$ 0
Independent Claims	3 - 3 =	0 x	\$ 78.00	\$ 0
Multiple Dependent Claims	0	0 x	\$260.00	\$ 0
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Please associate this application with the Hughes Electronics Corporation Customer Number 020991.
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**LINEARIZED TRAVELING WAVE TUBE CIRCUIT WITH PRE-
DISTORTION LINEARIZER**

09615019-071300

George Kirkman

Technical Field

The present invention relates generally to communication satellites, and more particularly, to a traveling wave tube circuit for communication satellites.

Background Art

Traveling wave tube amplifiers, or traveling wave tubes as they
5 are sometimes referred to, commonly consist of a vacuum tube RF high power
amplifier. In most applications for space systems, the high power traveling
wave tube amplifier is positioned some distance away from a predistortion
linearizer and electronic power conditioner due to the differing operating
temperature ranges of these devices. Commonly, the linearizer and power
10 conditioner use solid state components and therefore require a lower operating
temperature than the traveling wave tube amplifier. Commonly, an RF
interconnecting cable is used to couple the traveling wave tube amplifier and the
RF amplifiers and predistortion network. Such a device is shown in prior art
Fig. 1 having an RF input 10 coupled to an RF amplifier 12 which in turn is
15 coupled in series with a predistortion network 14. The predistortion network 14
is coupled to a second RF amplifier 16. The second RF amplifier 16 is coupled
to the traveling wave tube amplifier 18 by an RF connecting cable 20. The RF
amplifier 12, predistortion network 14 and RF amplifier 16 are located in a low
temperature zone 22. The traveling wave tube 18 is positioned in a high
20 temperature zone 24.

One problem with such a design is that the RF connecting cable
20 must be accounted for when performing an RF alignment of the linearizer
with the traveling wave tube amplifier 18. When the alignment is completed
with a specific cable length, any changes to the cable length may change the

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characteristics of the circuit and therefore the alignment process needs to be repeated.

Another drawback to the system is that the predistortion network is typically comprised of field effect transistors (FETs). These devices have
5 limited operating range for reliable operation.

It would therefore be desirable to provide a traveling wave tube amplifier and predistortion network circuit integrated as a single unit that does not require alignment if the cable length is changed.

Summary Of The Invention

It would therefore be desirable to provide an improved traveling
10 wave tube amplifier circuit that allows design flexibility for the spacecraft. It is a further object of the invention to provide a passive linearizer capable of operating at high temperatures to eliminate the effect of the RF connecting cable on the design of the circuit.

In one aspect of the invention, a traveling wave tube amplifier
15 assembly has a traveling wave tube, a predistortion network coupled to the traveling wave tube and physically coupled to the traveling wave tube. An amplifier is separated from the traveling wave tube and the predistortion network by a connecting cable coupled to the amplifier and the predistortion network. In a preferred embodiment of the invention, the predistortion network
20 and traveling wave tube are located in a high temperature zone and the RF amplifier is located in a lower temperature zone than the high temperature zone.

One advantage of the invention is that the cable length may be changed to accommodate various designs process without having to perform another alignment process.

Other objects and features of the present invention will become apparent when viewed in light of the detailed description of the preferred embodiment when taken in conjunction with the attached drawings and appended claims.

Brief Description of the Drawings

5 Figure 1 is a schematic view of a prior art traveling wave tube amplifier circuit.

 Figure 2 is a schematic view of a traveling wave tube amplifier circuit according to the present invention.

10 Figure 3 is a schematic view of a predistortion network of Figure 2.

 Figure 4 is a output power versus input power of the circuit of Figure 3.

 Figure 5 is a plot of the circuit of Figure 3 used in Figure 2 illustrating output power versus input power.

15 Figure 6 is transfer characteristic for a traveling wave tube showing output power versus input power.

 Figure 7 is an output versus input power plot of a linearized traveling wave tube using the circuit of Figure 3 and the transfer characteristics of Figure 6.

20 Figure 8A is a plot of $C/3IM$ or NPR plot versus output backoff that illustrates the linearized traveling wave tube characteristic of the circuit of Figure 7.

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Figure 8B is a plot of NPR versus output backoff of the circuit plotted in Figure 7.

Figure 9 is a schematic view of an alternative predistortion network according to the present invention.

5 Figure 10 is an output power versus input power transfer characteristic of the circuit of Figure 9.

Figure 11 is a transfer characteristic plot showing output power versus input power using the predistortion network of Figure 9 with a traveling wave tube having the characteristics of Figure 6.

10 Figure 12A is a plot of C/3IM performance of the traveling wave tube circuit of Figure 11.

Figure 12 is a plot of NPR versus output backoff showing the NPR performance of the linearized traveling wave tube circuit of Figure 11.

Detailed Description of the Invention

15 In the following description, the same reference numerals will be used to identify the same components in the various views. Although specific configurations are illustrated, those skilled in the art will recognize various alternative embodiments and configurations may be possible according to the teachings of the present invention.

20 Referring now to Figure 2, although other uses are possible, the present invention is illustrated with respect to a spacecraft generally represented by reference numeral 30. Spacecraft 30 has a traveling wave tube amplifier circuit 32 according to the present invention. The circuit 32 has an RF input 34

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that is coupled to a first RF amplifier 36. The first RF amplifier 36 has an output coupled to a second RF amplifier 38. Although two RF amplifiers are illustrated, those skilled in the art will recognize that a combination amplifier having the features of RF amplifier 36 and RF amplifier 38 may be formed.

5 An RF connecting cable 40 is coupled to the output of RF amplifier 38. RF connecting cable 40 couples RF amplifier 38 to a predistortion network 42. The predistortion network 42 is coupled physically to traveling wave tube amplifier 44. Also, the predistortion network 42 is coupled electrically in series with traveling wave tube 44 and the output of RF amplifier
10 38. The traveling wave tube 44 has an RF output 46.

RF amplifiers 36 and 38 are located in a low temperature zone 48 and predistortion network 42 and traveling wave tube 44 are located in a high temperature zone. For example, the low temperature zone may be about 65°C. High temperature zone 50 may, for example, be about 85°C. Thus, the
15 predistortion network 42 is separated from the components for RF amplification, namely the first RF amplifier 36 and the second RF amplifier 38.

Traveling wave tube amplifier 44 is preferably a vacuum tube high power amplifier. The traveling wave tube is a high power amplifier and operates efficiently at a high operating temperature such as the high temperature
20 zone 50.

Referring now to Figure 3, the predistortion network 42 is illustrated having an RF input 51, a limiter 52 coupled in series with the RF input. Limiter 52 is coupled in series with a first attenuator 54. The first attenuator 54 is coupled in series with a phase shifter 56 and the phase shifter 56
25 is coupled in series with a second attenuator 58. The operation of the limiter 52, attenuator 54, phase shifter 56, and attenuator 58 are well known in the art.

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Also, the predistortion network 42 has a transmission line 60 coupled in parallel with a series connection of limiter 52, attenuator 54, and phase shifter 56. Both ends of transmission line 60 are coupled to a ground termination 62. Predistortion network 42 is preferably formed of robust components such as PIN diodes that operate at higher temperatures than the field effect transistors (FETs). Advantageously, the predistortion network 42 may be located with the traveling wave tube 44 and the high temperature zone 50 that allows the independence of the circuit and the alignment process on the RF connecting cable 40.

- 10 Referring now to Figure 4, the transfer characteristic of the first limiter 52 is illustrated. As those skilled in the art will recognize, the transfer characteristics of the limiter 52 has power levels suitable for inputs to a traveling wave to amplifier. This eliminates the need for amplification stage 16 between the predistortion network and the traveling wave tube. As illustrated, 15 the relative phase is plotted with respect to output power. The bold line is relative phase; and, the thin line is output power. The elimination of amplifier stage 16 allows for operation at high temperature

- Referring now to Figure 5, when a linearizer having the transfer characteristics shown in Figure 4 is used in the circuit of Figure 3, the output of 20 predistortion network 42 shown in Figure 5 may be obtained.

Referring now to Figure 6, a transfer characteristic of a suitable traveling wave tube is shown. Both output power and relative phase are illustrated.

- 25 Referring now to Figure 7, when the traveling wave tube transfer characteristic shown is combined with the linearizer having a transfer

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characteristic shown in Figure 5, the traveling wave tube amplifier 32 is illustrated in Figure 7.

Referring now to Figures 8a and 8b, a traveling wave tube amplifier circuit performance is shown. In Figure 8a, the C3IM performance is illustrated for the amplifier circuit having the transfer characteristics shown in Figure 7. Also, Figure 8b illustrates the NPR transfer characteristics.

Referring now to Figure 9, the same reference numerals are used to illustrate the same components of Figure 3. An alternative embodiment of a predistortion network 42' is illustrated. In a similar manner to that shown in Figure 3, an RF input 41 is coupled with the series combination of a first limiter 52 and a first attenuator 54, a phase shifter 56 and a second attenuator 58. In addition, the transmission line 60 has a third attenuator 66 coupled in series with a second limiter 68. An attenuation of 5.5dB for third attenuator 66 was used in the predistortion network. Adjustment of the attenuator will allow the network 42' to be used with a family of different traveling wave tubes with input powers that vary ± 2.5 dB.

Referring now to Figure 10, the transfer characteristic of the predistortion network 42' is illustrated.

Referring now to Figure 11, the transfer characteristic of the traveling wave tube amplifier circuit 32 having a predistortion network 42' and a traveling wave tube characteristic 56 is illustrated.

Referring now to Figures 12a and 12b, the performance of the traveling wave tube amplifier circuit having a predistortion network 42' is illustrated. In Figure 12a, the C3IM performance is illustrated. In Figure 12b, the NPR transfer characteristic is illustrated.

In operation, because the predistortion network 42 is capable of being located within high temperature zone 50, the alignment process of the circuit is considerably reduced. Thus, once the circuit is formed and the alignment is performed, no further alignments are required if the length of the

5 RF connecting cable is changed.

While particular embodiments of the invention have been shown and described, numerous variations alternate embodiments will occur to those skilled in the art. Accordingly, it is intended that the invention be limited only in terms of the appended claims.

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What is claimed is:

- 1 1. A traveling wave tube circuit assembly comprising a
2 traveling wave tube:
3 a predistortion network RF coupled to the traveling wave tube
4 and disposed in the traveling wave tube;
5 an amplifier;
6 a connecting cable coupling the amplifier to the predistortion
7 network.
- 1 2. An assembly as recited in claim 1, wherein said amplifier
2 is disposed in a low temperature zone.
- 1 3. An assembly as recited in claim 1, wherein said
2 predistortion network is disposed in a high temperature zone.
- 1 4. An assembly as recited in claim 1, wherein said
2 predistortion network comprises a limiter.
- 1 5. An assembly as recited in claim 1, wherein said
2 predistortion network has a range between 11 to -3dBm.
- 1 6. An assembly as recited in claim 1, wherein said
2 predistortion network comprises:
3 a first limiter;
4 a first attenuator coupled in series with said first limiter; and
5 a phase shifter coupled in series with said first attenuator.
- 1 7. An assembly as recited in claim 6, wherein said
2 predistortion network further comprises a second attenuator coupled in said
3 series with said phase shifter.

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1 8. An assembly as recited in claim 6, wherein said
2 predistortion network further comprises a transmission line coupled parallel to
3 said limiter, said first attenuator and said phase shifter.

1 9. An assembly as recited in claim 8, wherein said
2 transmission line has a third attenuator.

1 10. An assembly as recited in claim 9, wherein said
2 predistortion network further comprises a second limiter coupled in series with
3 said third attenuator.

1 11. An assembly as recited in claim 1, further comprising a
2 second amplifier coupled in series with said first amplifier.

1 12. A traveling wave tube circuit assembly comprising:
2 a high temperature zone having a predistortion network; and
3 a traveling wave tube coupled in series with the predistortion
4 network;
5 a low temperature zone having an RF amplifier; and
6 an RF connecting cable coupling said low temperature zone and
7 said high temperature zone.

1 13. An assembly as recited in claim 12, wherein said
2 predistortion network comprises:
3 a first limiter;
4 a first attenuator coupled in series with said first limiter; and
5 a phase shifter coupled in series with said first attenuator.

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Abstract Of The Disclosure

A traveling wave tube assembly has a traveling wave tube and a predistortion network RF coupled and physically coupled to the traveling wave tube. The traveling wave tube and the predistortion network may be located in a high temperature zone. An amplifier located in a low temperature zone, is coupled to the predistortion network by an RF connecting cable.

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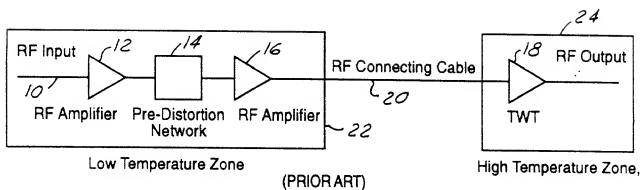


FIG. 1

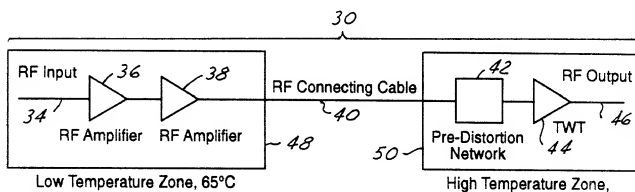


FIG. 2

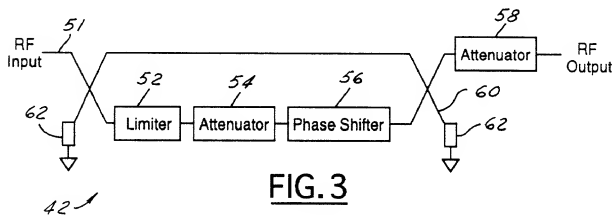
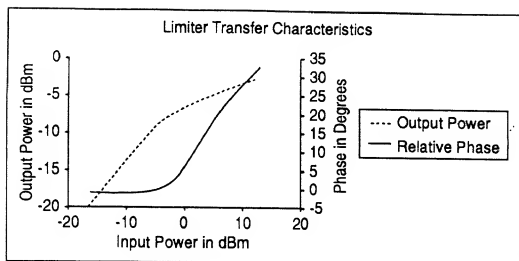
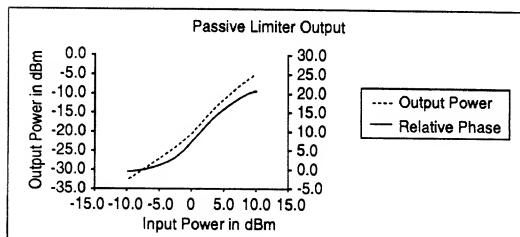
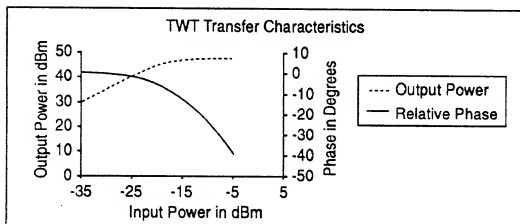


FIG. 3

**FIG.4****FIG.5****FIG.6**

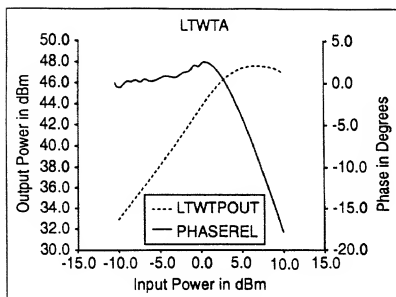


FIG.7

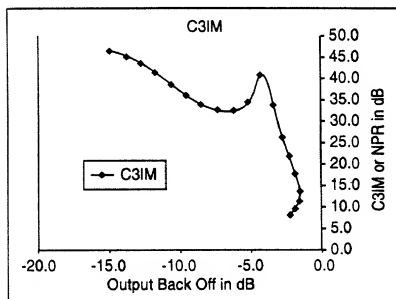


FIG.8A

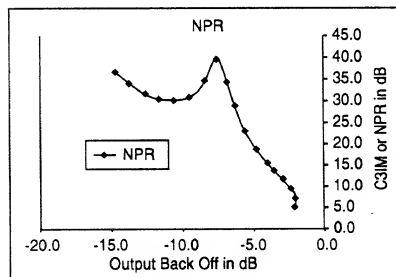


FIG.8B

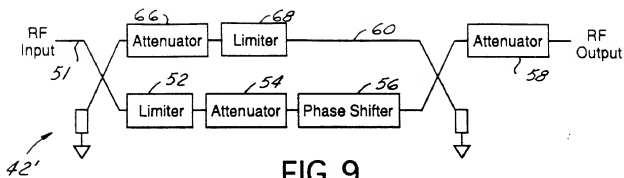


FIG. 9

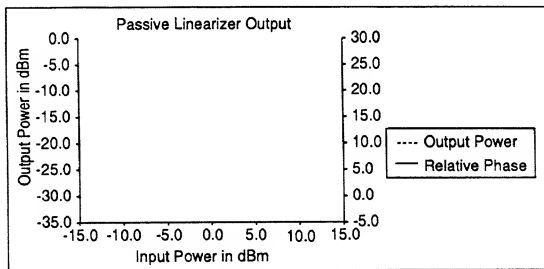


FIG. 10

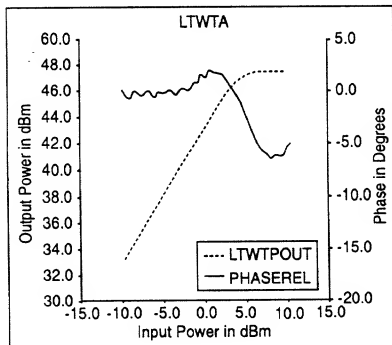
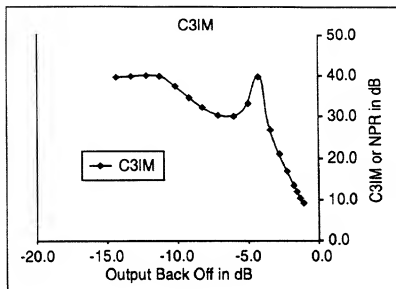
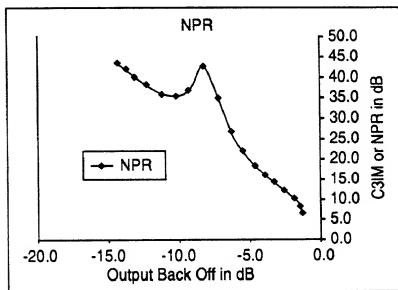


FIG. 11

FIG.12AFIG.12B



COMBINED DECLARATION FOR PATENT APPLICATION
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- ☒ Original
☐ Continuation
☐ Division
☐ Continuation-in-part
☐ Supplemental

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name.

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled **LINEARIZED TRAVELING WAVE TUBE CIRCUIT WITH PRE-DISTORTION LINEARIZER** the specification of which

(check one) ☒ is attached hereto.
☐ was filed on _____ as Application Serial No. _____ and (a) [other than supplemental] was amended on or (b) [supplemental] with amendments through _____.

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by an amendment referred to above.

I acknowledge the duty to disclose to the United States Patent and Trademark Office all information known to me to be material to patentability as defined in Title 37, Code of Federal Regulations, §1.56.

I hereby claim foreign priority benefits under Title 35, United States Code, §119 of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed:

Prior Foreign Application(s)

Priority Claimed

☐ Yes ☒ No

Number	Country	Day/Month/Year Filed
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I hereby claim the benefit under Title 35, United States Code, §120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code §112, I acknowledge the duty to disclose to the United States Patent and Trademark Office all information known to me to be material to patentability as defined in Title 37, Code of Federal Regulations, §1.56 which became available between the filing date of the prior application and the national or PCT international filing date of this application:

Application Serial No.	Filing Date	Status (patented, pending, abandoned)
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I hereby appoint the following attorneys, or agent and attorneys, to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith:

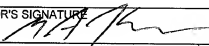
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I hereby declare that all statement made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such false statements may jeopardize the validity of the application or any patent issued thereon.

FULL NAME OF SOLE OR JOINT INVENTOR George F. Kirkman	INVENTOR'S SIGNATURE 	DATE June 26, 2000
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